International Journal of Bio-Science and Bio-Technology
Vol. 11, No. 1 (2019), pp.1-10
http://dx.doi.org/10.21742/ijbsbt.2019.11.1.01

Research status and Development trend of Plant Electrical signals at Home and abroad

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Abstract:

The present situation and future development trend of plant electrical signal at home and abroad are reviewed in this paper. The measurement technology, production mechanism and characteristics of the plant electrical signal and the change characteristics of the plant electricity under the external stimulation are briefly summarized. The basic characteristics of the plant electrical signal are: low frequency (<5 Hz), weak (μV), random non-stationary time-varying signal. breaking the password between the electric signal and the physiological state of the plant, which can lay a theoretical foundation for preventing and controlling the disease and the insect pest of the plant according to the electric signal of the plant, and can be used for producing the plant electrical signal in the near future, Life and related scientific research services provide some help.

Keywords: *plant electrical signal; time-varying signal; measurement technique*[1]

1. Introduction

China is a big agricultural country. As an effective development model of sustainable agriculture, precision agriculture has become a hotspot in agricultural scientific research in recent years. Precision agriculture is mainly to detect the physiological life information of plants. For plants, information acquisition is to obtain plant nutrient information, physiological and ecological information, pest information and disease information. Different scales are needed for obtaining physiological information. Scholars have put forward a new idea of rapid acquisition of life information from crop tissues, organs, individuals and groups and the development of sensing instruments, and from microcosmic to macro-scale, focusing on crop nutrient physiology, the researchers have put forward a new idea of rapid acquisition of life information from crop tissues, organs, individuals and groups. With the rapid detection of three-dimensional morphology and pest information, crop information sensing technology and sensing equipment have been developed. The key of disease control lies in early diagnosis. If plant disease can be found in early stage and early control, few pesticides are used and good control effect is achieved. The external visual symptoms and internal physiological conditions of plants are lagging behind in time. As the basis of regulation of plant physiological life activities, plant electrical signals can respond to stimuli in the first time. Since plant electrical signals are macroscopical reflection of important physiological information of plants, the study of plant electrical signals will be carried out in facility agriculture (optimal growth

[1] **Article history:**
Received (March 23, 2019), Review Result (April 24, 2019), Accepted (May 25, 2019)

environment), information agriculture (precision irrigation), Precision fertilization) plays an increasingly important role.

2. Measurement technology of plant electrical signal

It is the basis of studying plant physiological information to measure or detect plant signal in real time. The methods of plant physiological information detection are mainly lossy measurement and nondestructive measurement.

The non-destructive detection of plant physiological information can be divided into four categories: first, electrical signals: mainly for the detection of the degree of influence on the growth status of plants under stress, and the electrical signals are weak, the interference from the surrounding environment is large, the signal-to-noise ratio is low, and the detection stability is slightly poor; Second, machine vision and image processing: the judgment and analysis effect of plant appearance and morphology is good, while the detection of physiological factors inside the plant is weak. Third, spectral analysis and remote sensing: spectral analysis and remote sensing technology have been well developed and have achieved good results in detecting the inherent nutrients and moisture content of plants, but have insufficient advantages in determining and diagnosing the growth status of plants. Fourthly, chlorophyll fluorescence: fluorescence kinetic analysis technology in chlorophyll fluorescence analysis technology has better effect of monitoring plant growth status, but it cannot detect plant component content and physiological information. Damage detection of plant physiological information mainly refers to the measurement method that causes irreparable damage to plant cells or tissues and organs.

The measurement technology for plant electrical signals can be divided into three parts at different scales: ion channel hierarchy, cell level and macro level. Scholars have conducted purposefully research on the advantages and disadvantages of various measurement methods, which has promoted the research field of plant electrical signals again and again.

2.1 Ion channel hierarchy

The development level of plant electrical signal measurement technology is constantly accurate. The classic technology for channel level measurement is the diaphragm clamp technology, which mainly studies single cell ion transport. The new technology of research and development on this basis is the technology of plant ion flow rate measurement, which is non-damage micro-test technology, such as the in-situ validation of the important protein function by Professor Guo Yan in China, and the research results are published in the top-level journal. The patch clamp recording method is to use a special glass microelectrode to be adsorbed on the cell surface and used for recording the current of a single ion channel of the cell membrane, so that the contact with the cell membrane potential and the ion current can be established. SIET is based on the first law of Fick, and the ion concentration, flow rate and other information inside and outside the cell membrane of the in-situ living body are obtained through the ion selective microelectrode.

2.2 Cell level

Plant electrical signals are composed of electrical activities of individual plant cells. Microelectrode intracellular measurement technology is the most effective and direct way to measure the electrical activity of a single plant cell. The potential difference inside and outside the cell membrane and the change of membrane potential[1] can be obtained effectively by intracellular measurement. The intracellular microelectrode recording uses a glass microelectrode tip that is directly less than 1 um and can be inserted directly into a single cell to record changes in membrane potential at the individual cell level. In the cell level measurement technology from intracellular measurement to a new technology cursor non-contact measurement technology, it belongs to the non-contact method to record the electrical activity of multiple regions simultaneously. The optical recording method records the change of fluorescence intensity of plant cells impregnated with fluorescent dye, and then reflects the change of electrical signal through the change of fluorescence intensity. Its advantage is that it can record the electrical activity of the whole area. This method has no direct contact with plants and reduces the noise interference during measurement. The successful application case is the in vivo in situ plant electrical activity optical mapping system of China agricultural university[2].

2.3 Macro level

Extracellular measurement is the most common and simple method in plant electrical signal research. The commonly used electrodes for extracellular measurements are metal electrodes, surface electrodes and microelectrodes. The classic technique of extracellular measurement is to use special material clamps to measure plant leaves. Generally, metal electrodes are made of Pt,Ag and AgCl, which can be directly penetrated into plants for measurement, causing certain damage to plants, but the plants return to normal after a few minutes of acclimation. This method has high accuracy and can detect low frequency (under 5Hz) weak signals from plants[3]. Generally, the surface electrode is prepared by wetting the conductive solution with fine cotton thread, which can be directly attached to the leaves or stalks of plants for measurement without causing any harm to the plants. However, the evaporation of the conductive solution will affect the measurement to a certain extent. The microelectrode can be placed directly near the cell membrane without penetrating into the cell membrane to achieve the extracellular measurement of several or single cells. The new technique, (Multi-Electrode Microarray)MEA, is more accurate. In 2016, Professor Wang Z Y of China Agricultural University developed the seventh Macro-measurement of plant electrical signals, which are harmless to plants, anti-interference and easy to fix: colloidal salt bridge electrode coupling technology[4], and applied to Wheat Salt Tolerance screening. the group has developed a portable plant electrical signal measuring system, are capable of measuring the electrical signal curve shows, on the LCD screen display[4]. Extracellular measurements are generally recorded by macroelectrodes, which are used to record the electrical activity of population cells. The electrode tip diameter is generally larger than the cell diameter, and the electrical activity of several adjacent cells near the electrode can be measured. MEA recording method is a new implementation method which belongs to extracellular. Multi-electrode array can simultaneously record the electrical activity of multiple regions. It is suitable for observing the conduction law of plant electrical signals in large space and time scales.

3. Plant electrical signal analysis

3.1 Generation mechanism of plant electrical signals

About potential fluctuations in plants there are two basic theories: one is the "theory of bistable", put forward by Tasaki again in 1968, think membrane protein has a resting state and activity state two conformation. In resting state, the membrane molecules are compact in conformation and have greater selectivity for bivalent cations. In active state, the conformation is loose and the selectivity for bivalent cations is improved. Conditions conducive to the resting state of the membrane are the higher Ca2+/K+ or Ca2+/Na+ in the solution, while the higher Ca2+/K+ or Ca2+/Na+ makes the membrane in the active state and generates electrical signal transmission. This theory can be used to explain the transmission of salt-induced electrical signals. The patch clamp test confirmed the existence of Cl- and K+ channels on the internode membrane of chara. The generation of potential is also significantly affected by Ca2+. When the cell membrane is excited, the intracellular Ca2+ concentration increases. The intracellular Ca2+ concentration was increased due to the activation of Cl- channels on the membrane and the cessation of cytoplasmic ring. Voltage clamping test also confirmed the existence of[5]Ca2+ channel. In 1991, Julien[6]reduced the electric wave in Bidens pilosa intensity by 68% and 78%, respectively, with channel inhibitor La3 and Ca2 chelating agent (EGTA),It was also considered that the electric potential intensity was greatly affected by the activity of H pump. In 2016, professor Wang Z Y from China agricultural university pointed out the formation mechanism of plant electrical signals in detail and vividly with the ion mechanism model in his report on the collection and analysis of plant electrical signals, and listed the main ion contributions in plants during the process of wave potential depolarization and repolarization. For example, in depolarization, Cl- moves from inside the cell to outside the cell, Ca2+ moves from inside the cell to outside the cell, positive ions in the cell increase, and potential difference exists inside and outside the cell, forming action potential. When repolarization occurs, K+ channels open and K+ moves out of the cell, but there is not much elaboration on mercury ions here, which requires further exploration.

The transmission mechanism of plant electrical signal is consistent with that of animal bioelectrical signal, which depends on the long-distance transmission of bio-ion channel. Research on electrophysiology and other long-distance transmissions of signals in plants and animals has greatly contributed to our understanding of the biological world by revealing important similarities and differences between animals and plants. Humans understand that the underlying causes of this phenomenon may be related to their ability to respond to environmental stimuli. E.D. Brenner pointed out that in animals, lower plants and even higher plants, electrical signals play an important role in promoting respiration, photosynthesis, pollination and water conduction in sieve tubes during plant growth[7].

3.2 Plant electrical signal characteristics

Plant electrical signal is a kind of non-stationary and non-linear random signal closely related to plant life activities[8]. A weak, low-frequency signal. According to the study, it ranges from a few microvolts to dozens of millivolts. Plant electrical signals have time-varying characteristics: plants are in different growth stages, such as seedling and flowering stages; in different seasons, such as spring and summer, the response sensitivity and waveform amplitude are different[9]. The relationship between input (stimulus) and output (response) of plant electrophysiological system has the characteristics of nonlinear and unsteady. The response waveforms produced by the same stimuli are not easy to be completely consistent, but they are consistent when the characteristics of the stimuli are considered to be probabilistic[10].

Plant electrical signals can be divided into three categories[11]: System Potential (SP), Action Potential (AP), and Variation Potential (VP). The AP is a non-injury stimulus with "Full or None"-dynamic characteristics. Theoretically, when the external stimulus reaches the Fujian value, the AP and the AP can be induced to spread with a more stable propagation speed. The amplitude of the AP is generally in the range of several tens of mV to several hundreds of mV, and the duration is generally about several tens of milliseconds to about hundreds of seconds.

In addition, that AP is transmit along the bast part in the stem of the higher plant, and the transmission speed of the different plant AP is generally several mm/ s to several hundreds of mm/ s. VP is generated by injury stimulation, such as burns and shearing, etc., and its propagation speed is slower than AP, generally around 0.5-100cm/min[12]. With the increase of propagation distance and the attenuation of transmission speed, the repolarization process is longer and delayed. In 2009, Zimmermann et al. defined the electrical signal-system potential of plant apoplasts transmitted over long distances. They believe that the super-energy of cell membranes will be transmitted systematically through system potential[13].

3.3 Research Progress of Electrical Signals under External Stress

The perception of environmental information is the necessary mechanism of plant adaptation. Plasma membrane plays a key role in this perception, and the production of electrical response (the change of potential gradient on the plasma membrane) is an important part of the early response of plants to external stimuli.

In general, plant electrical signals can be induced by chemical[14] (water, herbicides, auxin) and external physical factors, such as light[15], heat[16], cold[17], cut[17], electrical stimulation[18], etc. But in fact, triggering electrical signals is an extremely complex issue[19]. First, the sensitivity of plants is closely related to the occurrence of electrical signals. Professor Lou divided plants into non-sensitive plants, semi-sensitive plants and sensitive plants according to their response to external stimuli. In non-sensitive plants, strong stimulation is required to trigger electrical signals, such as in watercress, burns, cuts, etc. In sensitive plants, a slight touch can trigger electrical signals: such as mimosa. Secondly, stimulators are also associated with the occurrence of electrical signals, and the types and intensities of plant electrical signals can be triggered by different stimuli. Among them, many researchers use burn as a more effective means of nociceptive stimulation. Thirdly, the physiological state of plants also affects the occurrence of electrical signals. However, the environmental conditions of plants are related to the physiological state of plants. In addition, it is worth noting that there is interaction between electrical signals in plants and other signals, such as hydraulic signals and chemical signals, but the mechanism of this interaction needs to be further studied.

3.3.1 Research progress of plant electrical signals under biological stress

From the perspective of plant pathology, the triangular principle of plant diseases[20]divides plant diseases into three factors: external environment, pathogenic microorganisms, and plant physiological characteristics. Thus the study of plant pests and diseases can also be carried out from these three aspects. In terms of the external environment: In 1973, Levitt pointed out that woody plants showed a physical phenomenon of reduced resistance after freezing stress, and appeared 48-48 h earlier than the symptoms appeared [21]. Through a lot of research, Professor Toriyama of Japan found that Acacia had obvious potential changes and strong currents under the stimulation of thunder, volcano and earthquake precursors. Su C B[22] studied the potential of the Acacia tree and its prediction of earthquakes. According to the analysis of scientists, the most sensitive plant before the earthquake is the mimosa. A few hours before a strong earthquake, the shy grasses would suddenly wither and then wither. In terms of pathogenic microorganisms, in 1956 Greenharm and Muller studied the conductance changes and responses of potato tubers after infection by different phytophthora and saussin [23], and found that the tubers infected by fungi had electric conductivity. Caruso et al. pointed out that the reduction rate of tomato taproot resistance was related to the virulence of pathogenic bacteria [24]. Zhou X M [25] et al. studied the transmission of electric waves in wheat by aphid syringe puncture technique. In terms of plant physiological characteristics, Shiina and Tazawa studied the effect of action potential of towel gourd on tendril elongation and growth in 1986 [26]. Hua B G [27] and other towel gourd was studied tendril movement and the relationship between the electrical signal transmission, the study found that no electrical signal transmission will not be able to complete speeding bending, towel gourd tendril tendril speeding bending are the result of actomyosin participation, b phthalein choline can greatly enhance the loofah tendrils response to mechanical stimulation, some even can directly induce curly movement. As early as 2008, PM Gil et al. [28]studied the relationship between moisture change and electrical signal in the environment of avocados. Electrical signal change is related to soil moisture, and is highly correlated with stomatal conductance reflecting stress degree. PM Gil, Saavedra J et al. [29] studied the relationship between soil water supply and electrical signals from a practical perspective in 2014. In 2016, Vladimir Sukhov[30] summarized the research progress in recent years on the effect of electrical signals on photosynthesis, the mechanism of action and its physiological role in plants. Joanna m. Nassar and Sherjeel m. Khan et al. [31] explored a wearable device in 2018 that integrates temperature, humidity and strain sensors and can be directly deployed on the soft surface of any plant to remotely and continuously assess the best growing environment.

3.3.2 Research progress of plant electrical signals under abiotic stress

Howink[32] summarized the previous work and divided the stimuli inducing plant electrical signals into nociferous and non-nociferous stimuli. It was believed that the former caused mutation potential and the latter generated action potential. Guo J [33][34][35] et al. studied the changes of electric waves in plants induced by non-noxious and nociceptive stimuli using healthy black pine seedlings as materials. Zawadzki, Davies and dzi-ubinska [36]; Stankovic, Zawadzki and Davies[37] et al. studied the characteristics of sunflower action potential and mutation potential respectively in 1991 and 1997. In 1997, Filek, ko-scielniak and Stankovic Davies studied the characteristics of electrical signals after injury to vicia faba seedlings and tomatoes respectively [38][39]. In 2001, Patrick, Hubert and Robert studied the variation of motion waves in arabidopsis thaliana after injury [40]. Shvehsova, mwesig-wa and Volkov studied the changes of action waves after soybean stimulation in 2001 [41]. American scholars Taitar and Blanchard pointed out in their summary in 1976 that plant electrical activity plays an important role in plant sensory and motor control. In 1984, Sakamoto and Sumiya studied the biological potential of young trees [42]. American scientist Gordon Jacobi found that tree rings also have the function of recording earthquakes. In 2000, an-dras, Laszlo and Viktor studied the changes of electrical signals of tree trunks in a year [43]. As early as 2008, pyatygin et al. found that action potentials are characterized by spikes in resting membrane potentials independent of stimulus intensity [44]. In 2013, Mousavi SA et al. [45] found that electrical signals under stress initiated the plant's own protection response.

With the continuous application and deep development of measurement technology, research on plant electrical signals has been able to penetrate into individual ion channels. Based on these measurement techniques, foreign scholars studied the electrical signal characteristics of drought stress, salt-alkali stress and other stresses of plants, and established their mathematical models through neural network and other algorithms. However, there are some problems in the current research. First, their acquisition system cannot be uploaded to the server through the network, and remote data transmission in Daejeon cannot be realized. Secondly, measuring the plant electrical signal should be a continuous, long-time acquisition process. The problem between the detection electrode and the plant coupling is becoming more and more prominent.

The aspect of finding a material with good loss and good coupling needs to be improved. Finally, a complete plant electrical signal model system is created, which can be used to extract the corresponding plant electrical signal model system according to the instruction when necessary.

4 Application prospect and prospect of plant electrical signals

4.1 Application prospects of plant electrical signals

The research on plant electricity still has a long way to go, and there is a lot of room for development. First of all, how to combine plant electrical signals with automatic production? It is completely new to combine the direct functional electrical signals of plants with automatic control technology to supply growth factors (such as water and fertilizer) in a timely manner according to the plant's own demand for growth factors (such as water and fertilizer). Intelligent self-adaptive control of water-saving irrigation based on "conversation between people and plants".

Secondly, how to use non-destructive testing of plants to detect the physiological state of plants. Decipher the adaptive characteristics of various plant electrical signals, use the plant's functional electrical signals to diagnose plant growth and development, and timely monitor and control the plant's pests and diseases in the reverse environment.

In addition, there are many environmental factors affecting plant growth. Therefore, it is very necessary to establish the database of plant electrical signals, establish the quantitative relationship between plant functional electrical signals and required growth factors, and construct the basic adaptive control system. It will be a new proposition for automation control experts to realize the regulation of greenhouse environment and extend it to crop field environment.

4.2 Prospects for plant electrical signals

For animals, we usually use EEG, ECG, body temperature, blood pressure and other parameters to characterize our physiological indicators, but whether plants, like humans, can use EEG, ECG, and so on. A parameter such as body temperature to represent its physiological index? It is generally known that higher plants have some physiological parameters such as photosynthesis, respiration, stomatal opening, transpiration rate, stem flow rate, leaf temperature, etc. By measuring whether these parameters can characterize physiological characteristics like humans, and then understand the growth and development of plants, To diagnose the physiological activation of plants and rationalize the cultivation management; Understand the impact of the external environment (physical, chemical, biological environment) on plants; study the electrical conductivity characteristics and control mechanisms in living organisms. If plant radio signals can be used as a reference basis for greenhouse production regulation factors, it will provide an effective means for dialogue between humans and plants, so that plants can become "talking plants" and change their growth environment based on their own changes. Since plant electrical signals are the macroscopic reflection of important physiological information of plants, the research on plant electrical signals will play an increasingly important role in facility agriculture and information-based agriculture.

Plant weak electrical signal information transmission exploration. Only by understanding the law of weak electrical signal transmission of plants, it is possible to establish the theory of biological information to explain many life phenomena and lay a foundation for the future development of high technology.

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Fund Project:The Key projects of Natural Science Foundation of Heilongjiang Province
Project NO. ZD2019F002